NWB Behavioral Tasks

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Overview and Scope

Behavioral tasks are an increasingly important component in neurophysiology studies, and are often considerably more complex than passive sensory studies. The description of behavior can be divided into stimulus sensory modality, behavioral contingencies, and behavioral outputs. In the current NWB format specification (release 2.2.5, May 2020), behavioral outputs can be stored as events (lick, nose poke), and the stages of a task (e.g. waiting period, cue period, reward period) may be stored as epochs. However there is currently no way to store descriptions of control flow and behavioral contingencies that provide critical context for how trial events and behavioral outputs produce subsequent actions within a trial. The scope of this proposal is to define an NWB extension to enable scientists to systematically describe behavioral tasks as part of a neurophysiology experiment.

Aims

- Use a standard markup language (BEADL) to build state machine descriptions of task logic and control flow within a trial and across trials in a session
- Define a set of essential metadata for common tasks
- Build a controlled vocabulary of key terms for behavioral tasks and construct a domain ontology
- Write a new schema extension for behavioral tasks in NWB
- Build software tools for visualization, construction, and emulation of tasks from these machine-readable descriptions

State machines for task modeling

State machines are ‘A model of computation consisting of a set of states, a start state, an input alphabet (inputs the SM responds to), and a transition function that maps input symbols and current states to a next state.’ (NIST). Typical uses are e.g. in software engineering, where state machines can be used to define the behavior of components in a GUI. State charts are a subset of state machines that allows hierarchical states and parallel processing within a state.

- Original Harel state chart paper: Statecharts: a visual formalism for complex systems
- Statechart tutorial: https://statecharts.github.io/

State machines are already used in some popular software packages for design and execution of behavioral experiments (Bpod, B-control, Ratrix). State machines are used to define the logic of single trials and the handling of signals and events within a trial. For example, Bpod was developed in Kepecs lab for use in control of behavioral experiments: “Bpod builds on the central design concept of B-control, a system provided by Brody Lab at Princeton University for

rodent behavior measurement. Experimental trials are constructed in MATLAB as finite state machines, and executed on a separate real-time Linux computer."

- State matrices in Bpod: https://sites.google.com/site/bpoddocumentation/bpod-user-guide/using-state-matrices
- Bpod Matlab protocol example: https://sites.google.com/site/bpoddocumentation/bpod-user-guide/protocol-writing
- B-control state machine definition: https://brodylabwiki.princeton.edu/bcontrol/index.php?title=Real-Time_Linux_State_Machine

BEADL

BEADL is a specification language for behavioral tasks that is currently being developed by current and former members of the Kepecs lab. The goal is to have a specification format that is machine-readable and executable (for testing/validation), with an included tool for building and visualizing task structure and control flow in a GUI.

- BEADL Specification Document

Out of scope

- **Other species:**
  - **Non-human primates -** We are focused on rodent task models (see use cases), however many behavioral studies involve NHPs and archives will include primate data. NWB should be able to accommodate these types of experiments, and there may be more diversity/complexity in primate tasks than those used in rodents.
  - **Humans** - Since NWB is an electrophysiology standard we probably won't handle much human data. However task structure and logic can have parallels with animal studies, and neuroimaging data models (e.g., NIDM) will have terminology and even task structure that differ from that used in animal studies. There are other schemas/ontologies for human tasks (see below), can we/do we want to keep some consistency?
- **Virtual/natural environments:** Referring to experiments where animals are allowed to explore an environment naturalistically, i.e. not a 'controlled' environment. Behavioral response may be measured from continuous pose or movement data as analyzed through e.g. DeepLabCut or other software for analyzing and classifying movement data. It is unclear how a State Machine description would apply to these studies (# of stimuli - inf, # of responses = inf?)
- **The 80/20 Rule**

Definitions

The terminology that will be used includes the following:

- **Task**:
- **State machine**:
- **Stimulus**:
- **Response**:
- **Reward:**
- **Instruction:**
- **Trial:**
- **Decision variable/decision rule**:
- **Lapse trial:**
- **Guess**:

Task metadata

Beyond the state machine for task logic/flow, we need fields for storing task metadata that is essential for data analysis.

- Stimulus metadata
    - Modality
    - Variable parameter values (for e.g. computing decision variables - contrast in contrast discrimination task)
    - Duration/timing of stimulus presentation
- Reward metadata
    - Modality
    - Value (amount rewarded)
- Signals/events that are not task-aligned
    - Motor output data (wheel running, wheel turning)
    - Pose data (from e.g. DeepLabCut)

Related Schemas and Data Models

- CogPO (http://www.wiki.cogpo.org/index.php?title=Main_Page) - human
- NeuroImaging Data Model NIDM (https://scicrunch.org/nidm-terms; https://github.com/incf-nidash/nidm-terms) - also human
- HBP openMINDS (https://github.com/HumanBrainProject/openMINDS) - just getting started
- odML (https://github.com/G-Node/odml-terminologies) - for animal studies, but also just getting started
- Datajoint's IBL schemas: https://github.com/int-brain-lab/IBL-pipeline

Use Cases

UC1: Allen Visual Behavior - Change Detection

This is a continuously-presented, flashed natural scene change detection task. For each trial, a natural image is presented for 250ms followed by 500ms of gray screen. On GO trials, a change in image identity occurs and mice must lick within the 750ms (one trial sequence) response window to receive a water reward. On CATCH trials, no stimulus change occurs (same image presented again) and the behavioral response is measured to quantify guessing behavior. To test whether expectation signals were present in the visual cortex during this task, ~5% of all non-change flashes were omitted.

Per session metadata:

- duration (~1 hr)
- image set (1 of 4)
- response window - time for reward availability
- timeout duration - extra time punishment for early responses
- min_no_lick_time - time with no licks to mark end of trial
- catch frequency - frequency of trials where no change occurs
- ...

Per trial metadata:

- change type (GO, CATCH)
- change time (time/frame number)
- next_image (image identity [0..7])

Articles:

  - Experience shapes activity dynamics and stimulus coding of VIP inhibitory cells
  - Training model: Quantifying and Modelling Transfer Learning in Mice Between Consecutive Training Stages of a Change Detection Task

UC2: Kepecs Lab - Confidence Reporting Task

This is a 2AFC task with a behavioral report of confidence. Rats poke in a center port and receive an auditory (stereo click train) stimulus. The difficulty of auditory decisions is varied by adjusting the balance of left/right rates in binaural streams of random clicks. Rats express their choice about stimulus identity by entering one of two side ports. On each trial, the reward is delayed by a random amount of time that is sampled on each trial from a truncated exponential distribution. Once rats have entered the choice port they have to wait until a reward is delivered or decide to give up and restart a new trial. In 10% of the trials, reward is withheld to measure how long the rats would have been willing to wait on correct trials.

Article:

- Behavior- and Modality-General Representation of Confidence in Orbitofrontal Cortex

Per trial metadata:
- trial type (reward given or withheld)
- stimulus delay - time animal must wait at home port before stimulus
- correct delay - time animal must wait for reward (0.6-8s, mean 1.5s)
- sampling time - the amount of time the animal sampled the stimulus
- movement time - the amount of time the animal spent in moving from the center port to the choice port
- time investment - the amount of time the animal invested without getting a reward

UC3: IBL - 2AFC/AUC and Contrast Discrimination Tasks

In the IBL protocol, head-fixed mice are trained to determine the location of a vertical grating on the screen and report their judgment by moving a wheel left or right, which moves the grating to the center of the screen. Grating contrast is varied to adjust task difficulty. There is an unforced choice variant of this task in which no grating is shown and the animal is rewarded for not responding. In addition there is a contrast discrimination variant where gratings are presented on both sides of the screen, and the mouse is rewarded if the higher contrast grating is moved to the center of the screen.

Per session metadata:
- duration (varies depending on task performance, 90min cutoff)
- reward volume (less reward used as mouse was better trained)

Per trial metadata:
- stimulus location (L/R)
- stimulus contrast (variable)
- inter-trial interval (variable, after stimulus offset)
- pre-stimulus quiescent period duration (variable, can be zero)

Articles:
- Pipeline paper: Standardized and reproducible measurement of decision-making in mice
- Methods paper: High-Yield Methods for Accurate Two-Alternative Visual Psychophysics in Head-Fixed Mice

Specs for control hardware: https://github.com/harp-tech/IBL_behavior_control

Additional Use Cases

- Frank Lab (n-AFC maze task designs):
    - Preprint: https://www.biorxiv.org/content/10.1101/2020.12.14.420174v1
- Reach-to-grasp task from Neo/Elephant paper

    - Handling Metadata in a Neurophysiology Laboratory | Frontiers in Neuroinformatics
- Interval tasks (2IFC, 2IUC)

Other Resources

UML and scXML (state chart XML) for state machine definition: These are existing standards for defining state machines, and are the formats used in many commonly-used software tools for working with state machines (MagicDraw, Yakindu).

- W3C: State Chart XML (SCXML): State Machine Notation for Control Abstraction
- Apache Commons (warning - dead links) - SCXML - Commons SCXML Usage - Five minute SCXML tutorial
- From Yakindu (state machine software tool) documentation: https://www.itemis.com/en/yakindu/state-machine/documentation/user-guide/scxml_integration
  'The XML defines all the states, transitions, events and variables used in the state machine. Besides the state machine's structural elements, the SCXML standard also defines the execution semantics of that state machine. And this is one of the biggest advantages of SCXML – the same statechart model can run on different SCXML engines on different platforms and it always behaves in exactly the same way – as long as the engines conform to the specified execution semantics.'

INCF SIG on neuroscience data structure: (Repository: INCF/neuroscience-data-structure: Space for discussion of a standardized structure (directory layout + metadata) for experimental data in systems neuroscience, similar to the idea of BIDS in neuroimaging)
This working group is aiming to coordinate efforts across multiple projects for data sharing (NWB, DANDI, eBrains, HBP). This includes associated projects for defining metadata terms, openMINDS and odML.

Existing NWB Components

At present, NWB has no dedicated fields for holding descriptions of behavioral tasks and metadata, outside of general fields for storing experimental descriptions/metadata. NWB does have components for storing behavioral epoch/event data:

- **BehavioralEpochs**: An interface for an IntervalSeries with timestamps delimiting epochs in the recording session. Epochs can be regularly spaced (rate) or irregularly spaced (individual timestamps).
- **BehavioralEvents:** BehavioralEvents is used for storing irregular events, like licks or nose pokes.
- **BehavioralTimeSeries:** BehavioralTimeSeries is for storing continuous behavioral data, e.g. wheel position in the IBL tasks.

- **SpatialSeries:** are used to store position or direction relative to a reference frame. Useful for e.g. maze tasks. **EyeTracking**, **CompassDirection**, and **Position** data interfaces store SpatialSeries data with the relevant reference frame (text)

Published Datasets

- AIBS Visual Behavior
  - Datasets: https://figshare.com/collections/Experience_shapes_activity_dynamics_and_stimulus_coding_of_VIP_inhibitory_cells/4858779/1

- IBL/Steinmetz Lab
  - IBL DANDIset: https://dandiarchive.org/dandiset/000045/draft
  - IBL Figshare: A standardized and reproducible method to measure decision-making in mice: Data
  - IBL Architecture paper: https://www.biorxiv.org/content/10.1101/827873v3.full.pdf+html
  - Steinmetz paper NWB data: https://figshare.com/articles/steinmetz/9974357

- DANDI archive examples/Buffalo Lab/others .... (?Links)

Work Plan

Jobs

- Controlled vocabulary and ontology definition
- Define list of essential/minimal metadata for tasks
- Build schema
- Data scientists to validate schema with example data
- Make extension, tutorial and outreach

NWB Extension

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Open Questions

- Is BEADL flexible enough to handle arbitrary tasks eg outside of Bpod/Bcontrol descriptions?
- Why not use DynamicTables for BehavioralEpochs in NWB (like is used for Epochs)? Would allow tags for labelling.

Topics and Issues to Address

Agenda and Discussion Notes (12/18/2020 - AIBS/Kepecs/NWB)

Agenda Items:

1) Introductions (5 minutes)
2) Overview of state machines for task modeling and goals (Pam - 20 minutes)
3) Overview of BEADL project and goals (Michael, Marion - 10 minutes)
4) Update on BEADL/NWB integration and goals (Michael, NWB team - 5-10 minutes)
5) Discussion of issues that arise, refine aims and work plan, set priorities for next steps (15 minutes)

- List your discussion topics in this section with your name
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- Some considerations for 'minimal' or 'essential' metadata (Pam):
  - What metadata would be required to replicate the experiment elsewhere?
  - Are metadata provided which may explain variability (e.g., between subjects or recordings) in the recorded data?
  - Are metadata provided which enable access to subsets of data to address specific scientific questions?
  - Is the recorded data described in sufficient detail, such that an external collaborator could understand them?